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INVESTIGATION OF THE DEPENDENCE OF THE EXPLODABILITY OF ROCKS ON THEIR PHYSICAL PROPERTIES DURING CRUSHING EXPLOSIONS

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Foreign Technology Division
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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}
rot	curl
lg	log

GREEK ALPHABET

Alpha	Α	α	α		Nu	Ν	ν	
Beta	Β	β			Xi	Ξ	ξ	
Gamma	Γ	γ			Omicron	Ο	ο	
Delta	Δ	δ			Pi	Π	π	
Epsilon	Ε	ε	ϵ		Rho	Ρ	ρ	ρ
Zeta	Ζ	ζ			Sigma	Σ	σ	ς
Eta	Η	η			Tau	Τ	τ	
Theta	Θ	θ	ϑ		Upsilon	Τ	υ	
Iota	Ι	ι			Phi	Φ	φ	ϕ
Kappa	Κ	ϰ	κ	ϰ	Chi	Χ	χ	
Lambda	Λ	λ			Psi	Ψ	ψ	
Mu	Μ	μ			Omega	Ω	ω	

INVESTIGATION OF THE DEPENDENCE OF THE EXPLODABILITY OF ROCKS ON THEIR PHYSICAL PROPERTIES DURING CRUSHING EXPLOSIONS

B. N. Kutuzov, V. K. Rubtsov,
V. F. Noskov; A. G. Tairbekova,
V. N. Zaxarov and A. M. Kudryavtseva

According to conventional terminology, by the concept of explodability is understood the resistivity of rocks to the action of explosion depending on the considered characteristic manifestation of the action of the explosion - shooting, fragmentation, or ejection - this concept is defined concretely with the indication of values of parameters accepted as standard. The characteristics of the explodability of rocks are the ratio of the weight of a charge of standard explosives to the volume of the zone of destruction, within the limits of which is observed the specified action of explosion; the formation of basin expansion, the crushing of cleavages by explosion into pieces of determined size or the formation of an ejection funnel with an index of action equal to unity. The boundaries of the basin cavity or the index of ejection can be easily and directly established by the measurement of linear dimensions, which provides an evaluation; for crushing explosions it is necessary to indicate the size of pieces and the method of measurement, since direct measurements are excluded here.

Rock is characterized by a complex of many properties of which only some are responsible for this type of destruction. So, during shooting explosions, obviously, the resistance of the rock to compression during the action of explosion gases can serve as such a single valued characteristic. It is possible to arrive at this derivation from the dimensional analysis of the parameters which determine the process, including examination the limit of strength of the rock:

ρ is rock density; E is Young's modulus; σ_{cm} is the limit of strength of the rock; d_e is the size of the cleavages; E_0 is the energy of the charge; D is the diameter of the concentrated charge; d_m is the maximum size of pieces after explosion; Π* is the radius of destruction.

Let us accept as parameters with independent dimensions ρ, d_m, and E_0. This is possible since the determinant composed from the indices of dimensions of these parameters is not equal to zero.

Dimensions of independent variables (in the system of practical units)

$$[\rho]=L^{-4}FT^{2},$$
$$[d_m]=L,$$
$$[E_0]=FL,$$

where L is the dimension of length, m;

F is the dimension of force, kg;

T is the dimension of time, s.

$$[E]=FL^{-2}=[E_0][d_m]^{-3};\ [d_e]=[d_m];\ [\sigma]=[E_0][d_m]^{-3};$$
$$[D]=[d_m];\ [R]=[d_m].$$

*Translator's Note. Symbol indistinct in original text. May be R or P.

By expressing the dimensions of the remaining parameters as independent and by converting to dimensionless quantities, let us find 5 criteria:

$$\Pi_1 = \frac{E}{E_0 d_m^{-3}},\ \Pi_2 = \frac{\sigma}{E_0 d_m^{-3}},\ \Pi_3 = \frac{d_e}{d_m},\ \Pi_4 = \frac{D}{d_m},\ \Pi_5 = \frac{R}{d_m}. \qquad (1)$$

We are interested in dependence $\Pi_5 = f(\Pi_1, \Pi_2, \Pi_3, \Pi_4)$.

From criterion Π_2: $d_m = \Pi_2 \sqrt[3]{E_0/\sigma}$.

After substituting value d_m into expression (1), we will obtain for the concentrated charge:

$$R = \sqrt[3]{\frac{E_0}{\sigma}} \cdot \Pi_2 \cdot f\left(\frac{E}{E_0 d_m^{-3}}, \frac{d_e}{d_m}, \frac{D}{d_m}\right)$$

or

$$R = \sqrt[3]{\frac{E_0}{\sigma}} \cdot \varphi\left(\frac{E}{E_0 d_m^{-3}}, \frac{d_e}{d_m}, \frac{D}{d_m}\right).$$

Hence the volume of destruction (of the basin cavity):

$$V = R^3 = \frac{E_0}{\sigma} \cdot \varphi'\left(\frac{E}{E_0 d_m^{-3}}, \frac{d_e}{d_m}, \frac{D}{d_m}\right).$$

Consequently, the volume of the basin cavity is inversely proportional to the compressive strength of the medium (Fig. 1).

The obtained theoretical result is a logical conseguence of the fact that the limit of their strength is accepted as the criterion for the resistivity of the rock. The sufficiency of this approach for internal action (camouflet) charges is confirmed by standard data of "Soyuzvzryvprom [Союзвзрывпром - Trust for Drilling and Blasting Operations]. From Fig. 1 we see that the value of the

index of shootability of a rocks is inversely proportional to their tensile strength. For stronger rocks this derivation requires supplementary experiments by virtue of the scantiness of data.

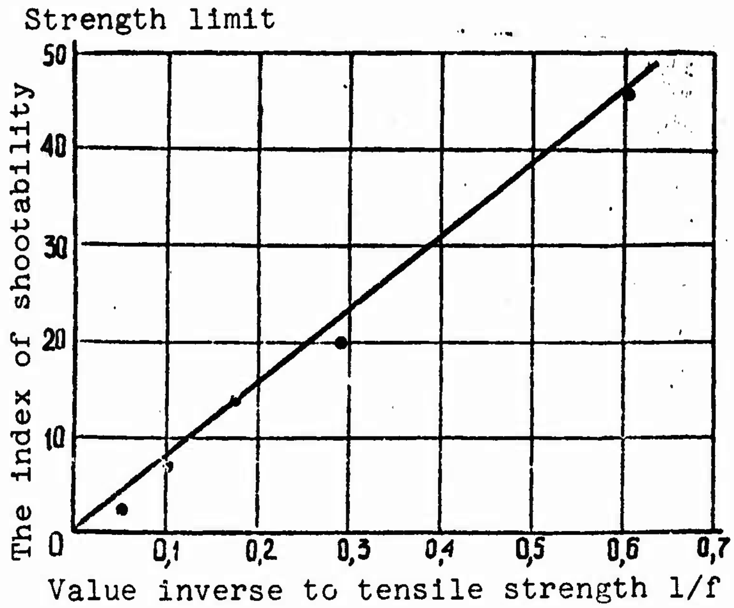

Figure 1. Dependence of the index of shootability on the tensile strength of rocks according to "Soyuzvzryvprom".

As for ejection explosions, the question is most fully studied in the works of K. I. Pokrovskiy, S. A. Davydov, et al. In them it is established that the value of calculated consumption of explosives (calculated coefficient in the Boreskov formula) is directly proportional to the specific weight of the rock; the available practical data, in our opinion, make it possible to consider this position sufficiently substantiated. The theoretical substantiation of this form of connection lies in the fact that with the formation of a visible ejection funnel the explosion overcomes in the gravitational field the total weight of the ejected volume of rocks, which is proportional to their specific weight.

As for crushing (loosening) explosions, the question concerning the properties of rocks was examined for the first time by M. M. Protod'yakonov [4], who on the basis of general considerations assumed that the specific consumption of explosives

is directly proportional to the tensile strength of rock, but he recommended additionally testing of this position.

Practice showed thatthe consumption of explosives during crushing explosions depends on the tensile strength of the rocks to a substantially less degree. Thus, we see that for crushing explosions it is not possible to extend the static solutions given above that, apparently, it is connected with the significant role of stress waves. In connection with this experimental explosions were made by the authors on models[1] (table) and blocks of rocks of essentially different physical properties.

Table. Parameters and results of explosions on sand-argillaceous cylindrical models of different strength.

Series of experiments	Compressive strength, kg/cm^2	Relative calculated consumption of explosives	Relative strength
I	30	I,00	I,0
	I50	I,62	5,0
II	I90	I,0	I,0
	340	I,I8	I,80
III	I9	I,00	I,0
	77	I,88	4,0

The calculated consumption of explosives is the ratio of the weight of the charge to the volume of the zone of destruction according to the definition given in work [6].

The data of these experiments confirmed the small effect of the strength of rocks on the rate of consumption of explosives, so, in the first series the 5 times distinction in strength caused a difference in calculated consumption of explosives in all 1.62 times; they show that calculated consumption of explosives in the first approximation is proportional to the fourth root of

[1]Yu. P. Yashin and V. F. Pluzhnikov took part in the work.

the tensile strength of rocks. Figure 2 gives the statistical data analyses of L. I. Baron [5] on 55 quarries of construction materials; they all are approximated well by dependence $q_0 \sim \sqrt[4]{f}$. Thus, we can arrive at the conclusion that during crushing (loosening) explosions the tensile strength of rocks exerts substantially less effect on the value of calculated consumption of explosives than during the formation of basin cavities. From this conclusion the insufficiency of known theoretical propositions and the need for supplementary experiments is apparent. One of the ways is the conducting of testing ground explosions in blocks of rock. Figure 3 gives data on explosions of monolithic outsize blocks in the quarry of AzGOK [АзГОК]* [acronym not found in available references]. The size of the blocks is 60×60 cm, explosions are carried out by a concentrated 50 g charge of ammonite 6ZhV in a bore-hole 42 mm in diameter. Explodability was characterized as the value of calculated consumption of explosives when the size of pieces was 150 mm. From Fig. 3 we see a regular increase of calculated consumption of explosives with an increase in the strength of the rock, which very approximately can be approximated by formula $q_0^{+150}=0.80\sqrt[4]{f}$. It is interesting to compare the result obtained from measurements with L. I. Baron's static data. The size of large pieces in the quarries, data of which entered into the statistics, is located in the range of 2500 mm. According to "methods of calculation" [6] the correction for the conditional size of pieces is equal to $(2300/150)^{2/5}=3$. Hence we have according to measurements $q_0^{+2500}=\frac{0.8}{3}\sqrt[4]{f}$ and according to static data $q=0.28\sqrt[4]{f}$. The data of these measurements did not show the presence of a connection between the specific weight of the rock and the value of calculated consumption of explosives for crushing. In connection with this special experiments were carried out on sand-cement cylindrical models 200×200 mm in size with different specific weight whose results confirmed the absence of a direct connection between the consumption of explosives and the specific weight of rock. Undoubtedly, the experiments in this direction must be continued

*Translator's Note. Possibly Azerbaydzhan Mining and Concentration Kombinat.

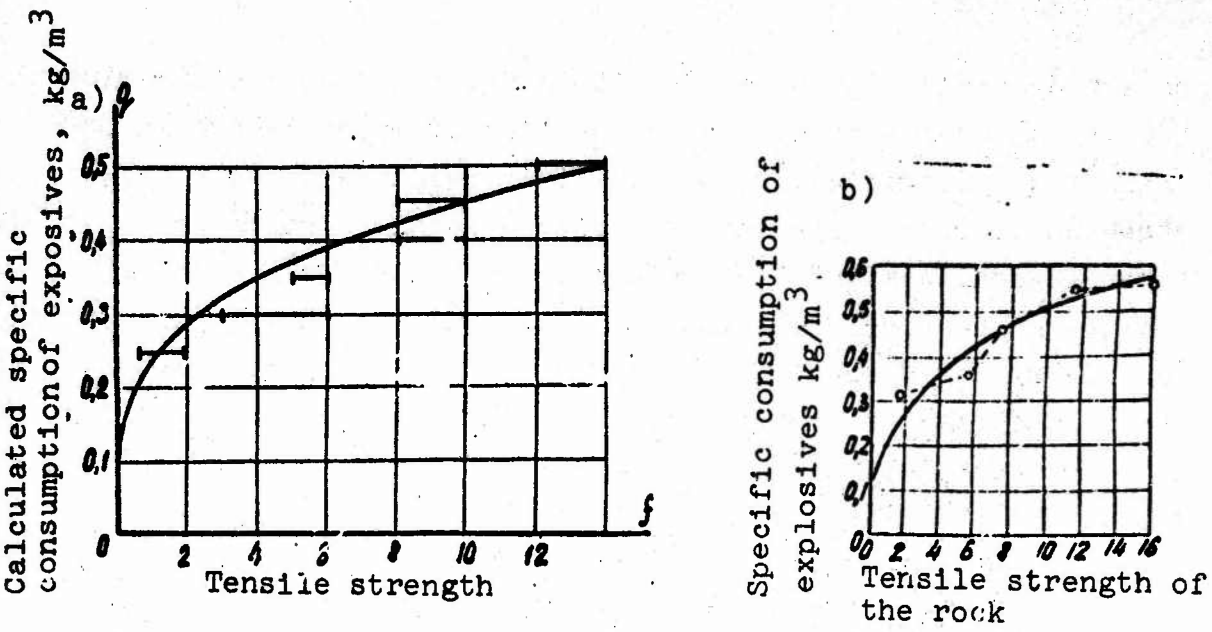

Figure 2. Dependence of the specific consumption of explosives in kg/cm^3 on tensile strength according to M. M. Protod'yakonov according to data of: a) "norms of technological design"; b) Prof. L. I. Baron and V. L. Baron.

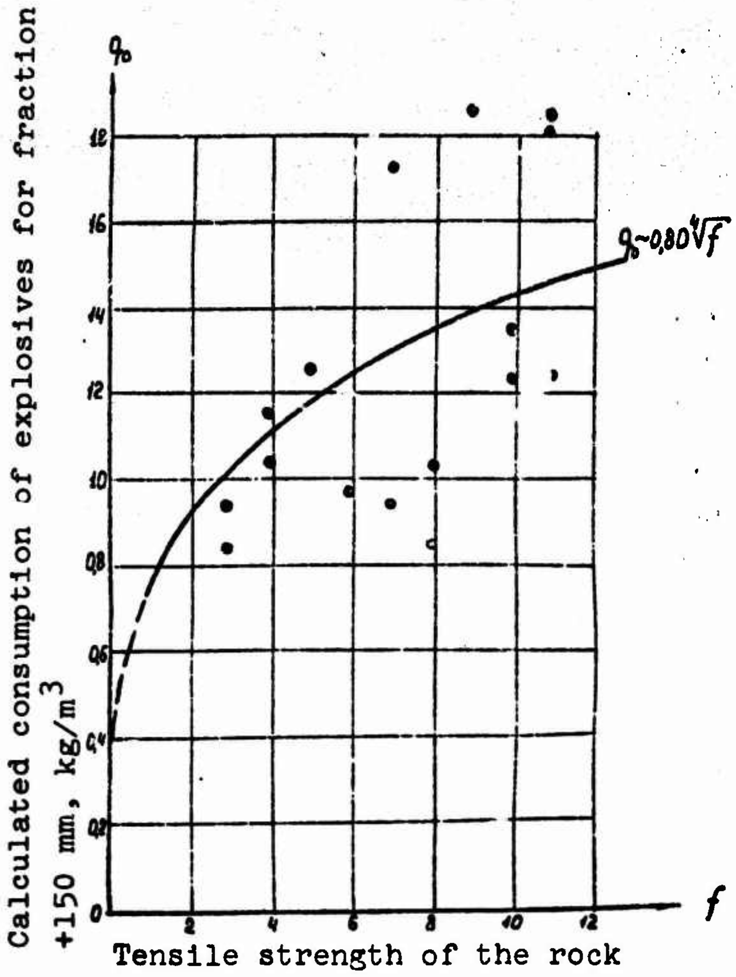

Figure 3. Dependence of calculated specific consumption of explosives on the tensile strength of rock according to results of explosions of outsize blocks in the quarry of AzGOK.

on a wide scale. In this case it is necessary to keep in mind that the basic physico-mechanical properties of minerals are interconnected. Specifically, the specific weight and the tensile strength of rock according to averaged data of "norms of technological design" [7] are connected by dependence $f=0.055\ \gamma^5$. Therefore the specific weight of rock during crushing explosions can affect not directly, but because of the interdependence with tensile strength. The generalization of the given data, results of other experiments, and the given "method of calculation" [6] for crushing explosions makes it possible to approximate them by the following empirical dependence:

$$q_0 = 0.47\left(\frac{1}{\lambda} + 0.2\right)\sqrt[4]{f}\,\theta\left(\frac{d}{500}\right)^{\frac{2}{5}},$$

where λ is the specific cracking of the rock massif, m^{-1};

f is the tensile strength of the rock;

θ is the conversion coefficient of explosives to ammonite 6ZhV;

d is conditional piece size, mm;

q_0 is the calculated consumption of explosives at conditional piece size d, kg/m^3.

The formula is recommended for calculations in the planning stage for escarpment cutting with drilling charges into a clear surface, maximum error will not be more than ±20%. The application of this formula to the experimental data on the quarries of the Kuzbass [Кузбасс - Kuznetsk Coal Basin] [8] showed the agreement of calculated and actual data with an error of ±9%. Introduction of other characteristics of the rock - Young's modulus, specific weight, Poisson ratio, etc. - into the calculated formula will make it possible to increase the accuracy of the calculations.

Conclusions

1. The explodability of the rocks with various forms of explosion work (shooting, crushing, and ejection) is determined

by their different physical properties.

2. The strength of rocks during crushing explosions has a relatively small effect on the value of calculated consumption of explosives; other conditions being equal, in the first approximation, the calculated consumption of explosives is proportional to the fourth root of the tensile strength of the rock.

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